;h Elm Disease and Its Management

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Cover:
Removal of an 80 year old American elm infected with Dutch elm disease. 1966.
H. V. Wester.

As the Nation's principal conservation agency, the Department of the Interior has the responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under the United States administration.

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Introduction

Despite nearly a half-century's exposure to Dutch elm disease, many elms continue to provide the graceful charm and stately character that numerous communities have grown to appreciate. In order to protect these remaining elm populations against Dutch elm disease, the entire community must be committed to this objective. Individual or localized efforts to protect separate parts of an elm population, e.g. a single yard specimen here, a street planting there, will not be successful when neighboring cultivated or wild elms harbor the disease and contaminate the entire population. Communities must, therefore, develop a unified, comprehensive, and sustained program to manage Dutch elm disease throughout all private and public sectors.

Program development should be based on a fundamental understanding of the disease and its management. Thus, the intent of this publication is to promote effective management of Dutch elm disease by fitting control measures to an accurate description of the disease.

This bulletin is based on information obtained from the literature and from experience gained in managing Dutch elm disease in the National Capital Region of the National Park Service. It is applicable to any community or agency responsible for Dutch elm disease management.

History

Few factors have had as great an impact on the urban landscape as Dutch elm disease. This has become by far the most devastating shade tree disease in North America. Our native American elm, *Ulmus americana* L., once an extensively used street tree throughout the Northeast and Midwest, is one of the most susceptible species. Prior to the introduction of the disease in 1930 there were an estimated 77 million elms in incorporated areas of the United States. As of 1976, 43 million (56%) had been lost, (USDA Forest Service 1977). Estimates have shown that removals and replacements of these valuable trees have cost as much as $100 million annually.

Although Dutch elm disease is believed to have originated in Asia, the first reported incidences were in the Netherlands and Northern France in 1919. Shortly thereafter, the disease was noted throughout most of Europe. At first it was surmised that diseased elms were casualties of toxic gases used during the First World War. Drs. Bea M. Schwartz, Christine Buisman, and other Dutch researchers later found the disorder to be caused by a fungus, now known as *Ceratocystis ulmi* (Buisman) C. Moreau. As a result of their research and valuable contributions to understanding the disease, the Dutch have had the unfortunate distinction of having the disease named for them.

The first confirmed diagnosis of Dutch elm disease in the United States occurred in 1930 in Cleveland, Ohio. However, it is most probable that the fungus first entered the country on elm veneer logs shipped from Europe to the port of New York, although it was not detected there until 1933. Dutch elm disease remained confined principally to the Northeast until World War II, when control measures were relaxed, allowing the disease to spread more rapidly. As of 1978 Dutch elm disease was reported in 42 states (Fig. 1). By 1947, the disease had reached Washington, D.C., where the first recorded case appeared on the Lincoln Memorial grounds (Fig. 2). During the next 30 years, Dutch elm disease reached epidemic proportions, necessitating the removal of over 10,000 elms within our Nation's Capital.

K. Wenskus

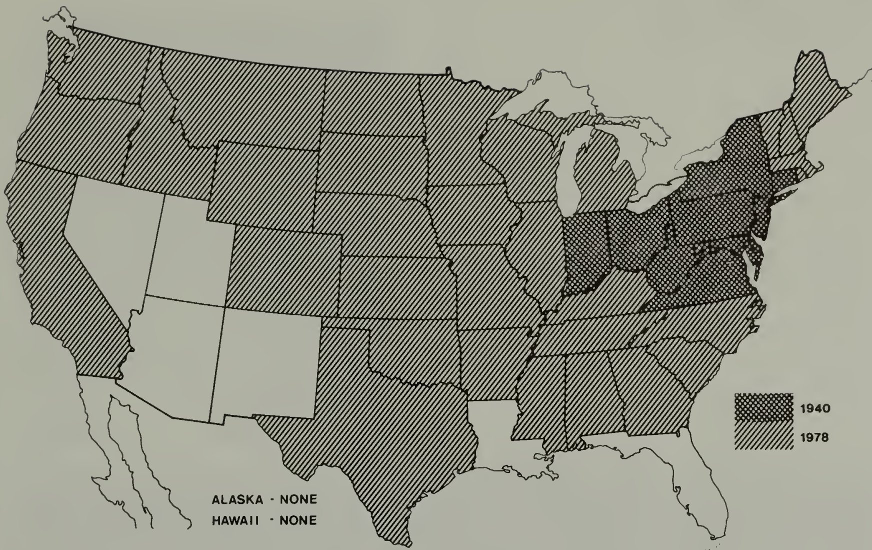

Figure 1. Distribution of Dutch elm disease in 1940 and 1978.

Figure 2. The first reported case of Dutch elm disease in Washington, D.C., was at the Lincoln Memorial in 1947.

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Symptoms

In typical cases, infected elms begin to wilt as early as the first week in May in the Washington, D.C., area. Wilt usually appears first in a single branch, which becomes limp and may assume a "shepherd's crook" appearance. Leaves curl, turn yellow, and then begin to brown, producing what is commonly referred to as a "flare" (Figs. 3, 4). Dried leaves may remain attached to the limb or may fall, leaving bare twigs.

As the infection progresses, the entire limb begins to wilt. Once the infection reaches the trunk it then moves throughout the tree, often resulting in total wilt and death of the tree within a year (Fig. 5). In some cases, especially in older trees, the disease can develop as a chronic disorder progressing slowly through the tree for several years before death occurs.

Internally, infected twigs, limbs, and trunk often exhibit brown streaking of the outer sapwood (Fig. 6). Streaking develops from deposits of gummy substances in the xylem (water conducting) tissue. Since other wilt diseases, such as *Cephalosporium* and *Verticillium,* also show wood streaking, absolute diagnosis can be made only by identification of the fungus isolated from the infected tree. To do this, fresh twig samples (1/2 by 6 inches) should be taken from wilted limbs and submitted to an extension plant pathologist for the isolation and identification of the pathogen (Fig. 7). However, in areas where Dutch elm disease has been previously identified, most cases of elm wilt are a result of Dutch elm disease infection and the isolation, culture, and identification of the fungus is not needed prior to action.

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Figure 3.
Branch exhibiting wilt and leaf discoloration.

Figure 4.
Elm exhibiting a crown "flare".

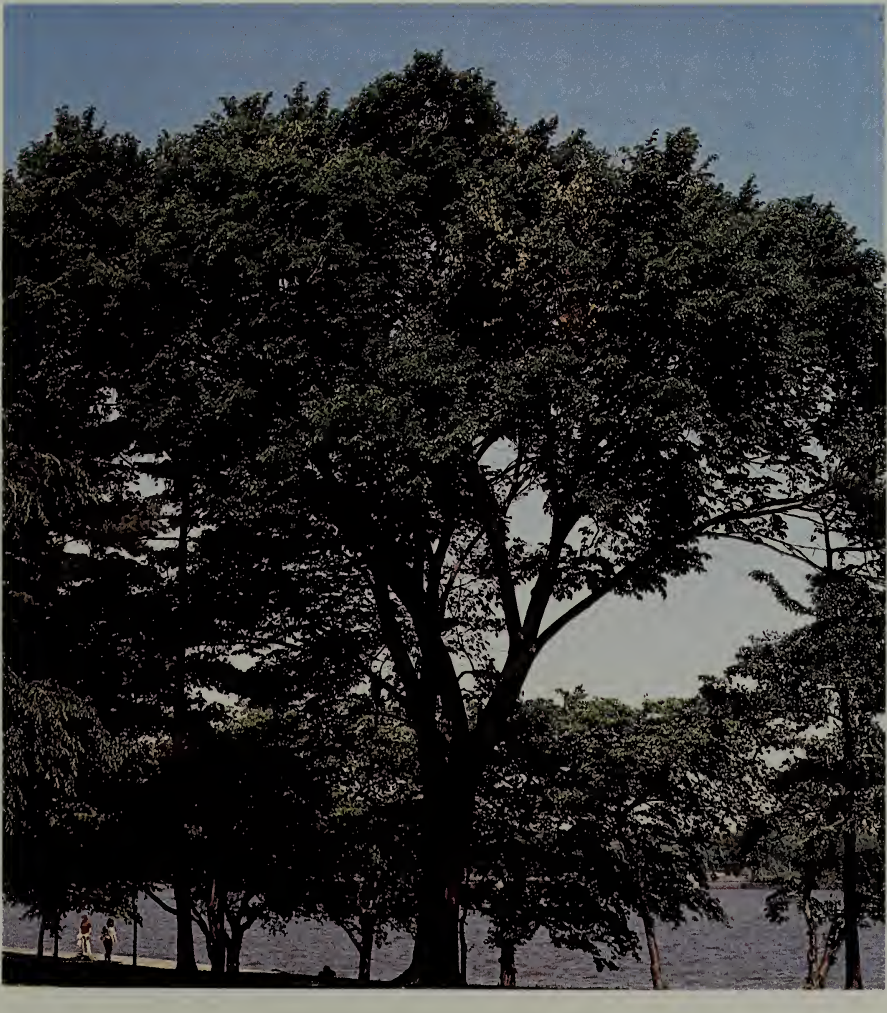

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Figure 5.
(Above) Large elm severely infected with Dutch elm disease.

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Figure 6.
(Right) Sapwood discoloration. Top twig is infected, bottom twig appears healthy.

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Figure 7.
Culture of *Ceratocystis ulmi* from elm wood chips.

Pathogenesis

The fungus enters the elm as microscopic asexual spores called conidia. Conidia are introduced into the outer xylem through feeding wounds made by the elm bark beetle. Conidia reproduce in the xylem tissue by yeast-like budding and spread via the sap stream throughout the tree. The conidia also produce thread-like structures called mycelia which ramify throughout the xylem cells, producing more conidia. Elms respond to infection by developing tyloses—intracellular protrusions—which block the water-conducting vessels. Tyloses, as well as masses of conidia and mycelia, gums, and fungal related toxins, are all believed to play a role in restricting water movement in the tree, resulting in wilt and eventual death.

Trees are most susceptible to Dutch elm disease in the spring and early summer, when xylem vessels are large and offer minimal restriction to the spread of the fungus. Vessels formed later in the summer are smaller and restrict rapid spread of the fungus. Thus, late infections spread slowly and may easily go undetected. These latent infections may then develop rapidly the following spring.

Transmission

Insect Vectors

The smaller European elm bark beetle, *Scolytus multistriatus* (Marsh.), and the native elm bark beetle, *Hylurgopinus rufipes* (Erchh.), are the primary insect vectors known to transmit Dutch elm disease in the United States. The European elm bark beetle is the most prevalent vector in the Washington, D.C. area. It is believed that these beetles first entered the country on veneer logs or on wooden crates shipped from Europe. The European beetle was first reported in the United States in Boston, Massachusetts, in 1904 and is now found in nearly every state.

Beetles breed beneath the bark of dying or recently dead elms. Declining or stressed elms emit an attractant which stimulates breeding attacks. While boring into the bark of brood trees, virgin females release two other attractants, or pheromones, which lure thousands of additional male and female beetles to the brood tree. The female lays as many as 100 eggs in two rows along a vertical gallery between the bark and the wood of the tree. Eggs hatch in about a week, producing white, legless larvae, or grubs, which bore tunnels perpendicular to the egg gallery (Fig. 8). Larvae tunnel for 4 to 5 weeks before developing into pupae. Adults develop from the pupae in 1 to 2 weeks and emerge from the bark through pin sized holes (Fig. 9). Adults are shiny red-brown and approximately 1/8 inch long (Fig. 11).

In most areas, beetles go through two breeding cycles between May and September. The first period, or spring emergence, consists of adults that develop from overwintering larvae. In the Washington, D.C., area, the spring emergence begins in April and is usually completed by the end of June. The second, or summer emergence, develops from the progeny of the spring adults with emergence occurring throughout the latter part of the summer. There are usually 3 to 5 times as many beetles emerging in this latter period. In areas such as Washington, where the weather remains mild, a third but lesser emergence may occur in the fall.

Beetles emerging from trees dying from Dutch elm disease are often covered with the sticky fungal spores. The spores are produced on fungal

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Figure 8. Gallery formed by the smaller European elm bark beetle. Eggs are laid along the maternal gallery, which the female tunnels along the grain of wood. The lateral galleries are tunneled by the developing larvae.

Figure 9. Emergence holes of the smaller European elm bark beetle.

Figure 10. Coremia of *Ceratocystis ulmi.*

C. A. Sheets

fruiting structures called coremia (Fig. 10), which are commonly found in bettle galleries and pupal chambers. Upon emergence spore laden beetles fly to nearby elms, where they feed on elm twig crotches (Fig. 11). It is through beetle feeding that spores become deposited within the xylem tissue of healthy elms, initiating the Dutch elm disease infection.

Root Graft

The only other natural means by which Dutch elm disease can be spread is by root graft transmission. Roots of closely spaced elms often fuse to form natural grafts between adjacent trees (Fig. 12). Conidia present within the vessel elements of diseased trees are translocated via the sap stream through the root graft and into the healthy tree. In many communities where elms are planted within 50 feet of each other, root graft transmission is believed responsible for the sequential infection and death of hundreds of trees.

Mechanical

Man himself may also be a vector for Dutch elm disease. Pruning tools used to remove diseased trees and limbs can become contaminated with fungal spores. When contaminated tools are used to prune healthy trees, infection may occur. Unnecessary mechanical inoculations can be avoided by sterilizing pruning equipment with either denatured alcohol or clorox whenever contact with diseased tissue is suspected.

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Figure 11. Smaller European elm bark beetle feeding in elm twig crotch.

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Figure 12. Root graft formed between two adjacent elms.

Management Techniques

Sanitation

Efficient and thorough sanitation is believed to be the most effective means of reducing the vector population and sources of fungal inoculum. Sanitation involves the detection, removal, and destruction of potential and active brood wood. This includes dead or dying trees as well as dead or dying limbs on otherwise healthy elms.

A Forest Service study has shown that intensive sanitation is significantly more effective in limiting the spread of Dutch elm disease than conventional sanitation practices (Barger 1977; Cannon et al. 1977). Intensive sanitation involves disease surveys in June, July, and August, and the removal of diseased trees within 20 working days after detection. Conventional sanitation, which is commonly practiced by many municipalities, involves only one disease survey and the removal of diseased trees in the fall and winter.

In addition to cultivated elms, scouts should also examine natural elm stands that are close to cultivated trees. Brood wood must be destroyed immediately by chipping, burying, burning, or debarking.

Sanitation can be performed chemically with the herbicide cacodylic acid (Silvisar 510). Cacodylic acid is applied to cuts around the trunk or is injected into root flares of brood trees. Treatments should be made while the tree is in leaf to allow translocation of the chemical throughout the tree. Cacodylic acid causes rapid wood dessication, which kills beetle eggs and larvae, preventing the development and emergence of adult beetles. Chemical sanitation can be used on trees in natural areas, where removal is difficult, or on street and landscape trees which cannot be removed quickly.

Insecticide

Although sanitation is the most important control measure, additional control can be achieved through insecticide applications. A combined sanitation and spray program should limit the incidence of new infections to less than three percent if instituted before the disease reaches epidemic proportions.

Shortly after World War II, DDT was used routinely for Dutch elm disease control. However, because of its extreme persistence and indiscriminate threat to the environment, further use of the pesticide in the United States was prohibited in 1968.

Methoxychlor, an insecticide that is less persistent and 1/25 to 1/50 as hazardous to wildlife as DDT, is now routinely used. Methoxychlor is applied as an emulsifiable concentrate with either a mist blower or hydraulic sprayer. An application in late winter or early spring before trees are in leaf permits thorough coverage of twig crotch surfaces. It is important to remember that only trees receiving complete coverage will be adequately protected. Coverage is highly dependent upon the experience of the applicator.

Spray Specification

Mist Blower:	For a 12 1/2% Active Ingredient solution mix 50 gallons 25% EC Methoxychlor + 50 gallons of water 2–3 gallons of mix/50′ tree
Hydraulic Sprayer:	2% Active Ingredient 8 gallons 25% EC Methoxychlor + 92 gallons of water 20–30 gallons of mix/50′ tree

Spraying should be performed when wind speed is less than 5 MPH and the temperature is above 32°F. At least 24 hours notice should be posted so that motorists will avoid parking along the spray route.

Biological Control–Elm Bark Beetle

Recent progress has been made in the biological control of the smaller European elm bark beetle. Scientists have successfully isolated and identified the three chemicals (one produced by the host and two produced by the virgin female beetle) responsible for luring beetles to brood sites (Pearce et al. 1975). These compounds have been synthetically produced and combined to form the aggregating attractant, Multilure (attracts both male and female beetles). Multilure is currently being evaluated as a bait for beetle traps (Fig. 13). The ultimate objective is to develop a trapping system that will suppress beetle populations sufficiently to reduce the incidence of Dutch elm disease. Beetle trapping is currently experimental. However, such a technique may prove valuable in an integrated Dutch elm disease control program.

Prevention of Root Graft Transmission

Root graft destruction is most critical in areas where trees are growing within 50 feet of each other. Root graft control is time consuming and need only be performed where a diseased tree is found. In addition to destroying grafts between diseased and healthy trees, grafts between the first and second closest tree should also be destroyed to provide a sec-

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Figure 13. Sticky paper trap baited with smaller European elm bark beetle attractant, Multilure.

H. V. Wester

Figure 14. Trenching for disruption of root grafts between adjacent elms.

ondary barrier in case the infection has already spread to the tree adjacent to the diseased tree. Two techniques are used to destroy grafts. When feasible, a trench 36 to 40 inches deep can be made between trees with a mechanical trencher (Fig. 14). Since most sizable roots are within 2 feet of the surface this technique will sever nearly all root grafts. The trench can be backfilled immediately after it is dug. Care must be taken to avoid underground utilities.

Grafts may also be destroyed chemically with the soil fumigant Vapam (VPM-Dupont) or SMDC (Stauffer Chemical Company). Holes 3/4 to 1 inch in diameter and 15 to 30 inches deep are drilled 6 inches apart beyond the drip line. One part Vapam 32.75% is mixed with three parts water. One cup of the mix is placed in each hole, avoiding overflow at the top. The holes are then sealed with soil, confining the fumigant to the root zone. Vapam is most effective at temperatures above 50°F. and when the soil is not waterlogged. Since Vapam is nonspecific, it should not be applied within 5 feet of shrubs or 25 feet of other trees. It takes approximately 2 weeks for Vapam to effectively stop sap flow between grafted root systems. Vapam will also kill grass around the injection hole. Grass can be reseeded or resodded the following year.

Root grafts must be destroyed before removing the diseased tree. If trunks of diseased trees are severed before root grafts are destroyed, there may be a sudden backflow of fungal infested sap into the healthy tree.

Fungicides

The internal systemic nature of vascular wilt disease prohibits control via conventional foliar fungicide application. Recently, however, advances have been made in the internal application of fluids into trees. Gravity flow and pressure injection techniques are currently being used to direct fluids into the vascular system. In the case of vascular infections, injection techniques facilitate the rapid delivery of large volumes of fungicide to the infection site while avoiding the waste and environmental contamination associated with conventional spray procedures.

Formulations of the systemic fungicides Lignasan—BLP, Dupont; and 'Arbotect' 20-S, Merck and Company, Incorporated, have been registered by the Environmental Protection Agency for use in both preventive and therapeutic injection treatments. Preventative injections are costly and must be repeated yearly, while therapeutic injections have the greatest chance of success for infections involving 10 percent or less of the tree. Recent evidence indicates that repeated trunk wounding for injection may seriously harm the tree by providing avenues of infection leading to wood decay. Fungicide injections should still be considered experimental and used only in conjunction with proven control measures.

Pruning

A simple measure that can be taken to save diseased elms is the *rapid* removal of infected tissue as soon as detected. Surgery must remove not just the visible wilted tissue, but all tissue harboring the fungus which may not yet be exhibiting external or internal symptoms. The degree of surgical success has been correlated with the distance between the discolored wood and the pruning cut (Fig. 15). It has been shown that 87 percent of the trees with greater than 10 linear feet of apparently disease-free wood between the pruning cut and discolored wood were saved. Only 12 percent of the trees having less than 5 feet were saved (Campana 1975).

It is apparent that in most cases radical pruning back to the next major crotch or main trunk is necessary. Radical pruning may often be hard to accept. However, when the alternative of losing the tree is considered, such action is more than justified.

The most effective therapeutic approach involves a combination of pruning and fungicide injections (Gregory and Allison 1979; Sherald and Gregory 1980). When possible, the limb, as well as the trunk, should be injected, followed by pruning of the diseased limb 2–10 days after the injection.

Intensive therapy is expensive and should be reserved for high

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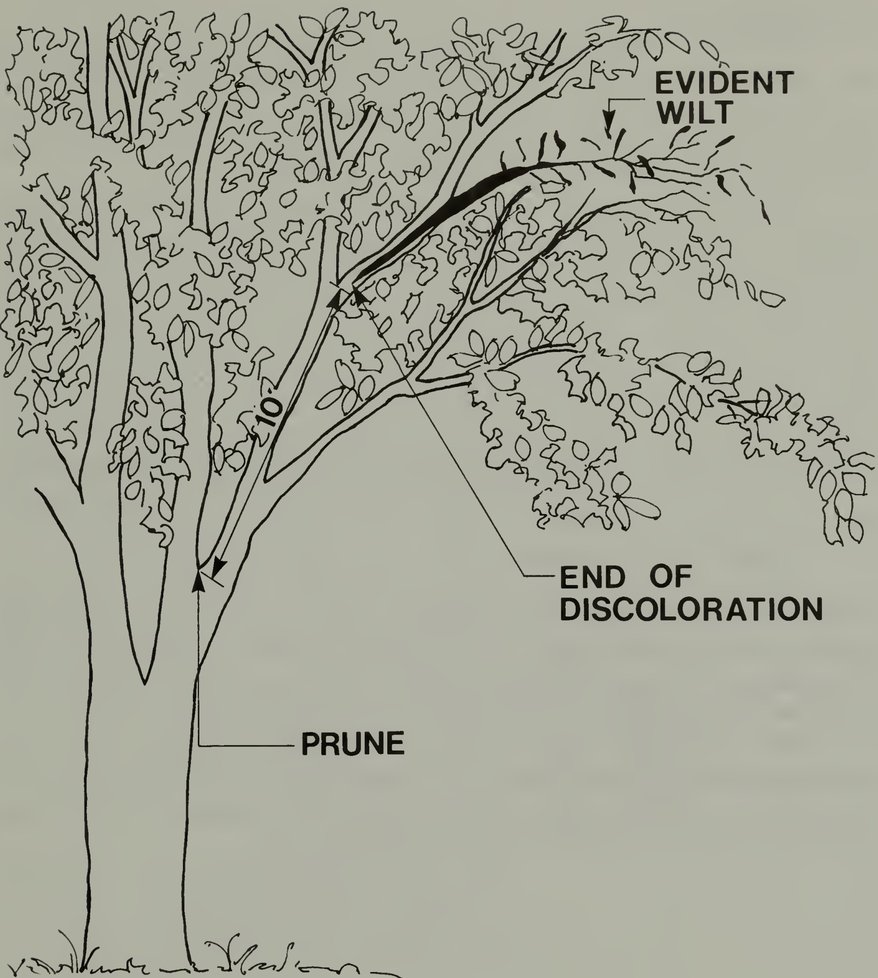

PRUNING THERAPY

Figure 15. Successful pruning therapy depends upon the length of clear wood between the last point of visible discoloration and the pruning cut.

value landscape or historic specimens with infections limited to 10 percent or less of the crown. Poor-risk trees—those with greater than 10 percent wilt, older trees with deteriorating crowns and generally poor vigor, or trees that would be aesthetically unacceptable after radical pruning—should not be treated. Appendix I summarizes the disease cycle and management measures by month.

Resistance

The most effective and efficient means of avoiding any disease, parasitic or nonparasitic, is by selecting resistant plant material. The costly demise of elm plantings in the Northeast and Midwest has stimulated many communities and homeowners to search for street and shade trees that are disease tolerant and easy to maintain.

Much effort has been directed toward breeding and selection of elms tolerant to Dutch elm disease. Asiatic elms are the most resistant species within the genus. However, they bear little resemblance to the wide spreading, vase-shaped American elm. European elms, thought to be more tolerant to Dutch elm disease than the American elm, have recently shown severe susceptibility to an agressive strain of the Dutch elm disease pathogen. Aggressive strains are believed to be widespread in the United States. The blending of the American elm form with Asiatic elm resistance through breeding has long been hindered by an incompatibility in chromosome numbers. Recent advances in plant breeding may soon overcome this incompatibility. Appendix II lists elms susceptible and resistant to Dutch elm disease.

Reliance on any one species, no matter how tolerant to a particular disease, is at best risky. Monoculture, the mass planting of a single species, provides a condition for the rapid spread of disease or insect devastation. Diverse plantings provide a more natural control environment, with minimum risk of extensive tree losses from any one factor.

The American elm will never be as prominent among urban tree plantings as it once was. However, if communities are willing to sustain a comprehensive Dutch elm disease management program, the elm can continue to play a valuable role in the urban forest.

Appendix I

Summary of the disease cycle and management measures for Dutch elm disease.

	Disease Cycle	Management Measures
February		Methoxychlor is applied in late winter or early spring before the first generation of beetles begins to emerge and feed. Applications must be made when temperatures are above freezing.
March	As temperatures rise, overwintering larvae begin to complete their development.	
April	Larvae develop into pupal cells. Pupae develop into adults in 1–2 weeks.	
May	The spring generation of bark beetles begins to emerge from overwintering brood sites. Many are laden with spores of *C. ulmi.*	Begin examining elms for symptoms of Dutch elm disease. Rapidly remove and destroy all diseased elms.
	Beetles feed in 3–4 year old twig crotches of healthy elms, initiating new infections.	Radically prune minor infections, removing at least 10 feet of clear wood. Destroy root grafts where necessary.

May (cont.)	Disease Cycle	Management Measures
	Elms are most susceptible to Dutch elm disease in spring and early summer.	
	Infected elms begin to wilt.	
June	Spring emergence begins to decline.	Continue scouting and sanitation.
	Feeding adults continue to infect healthy elms.	Remove as much brood wood as possible before the second, or summer, emergence begins.
	Adults begin to breed in diseased elms. New adults develop from eggs in approximately 6 weeks.	Continue to destroy root grafts where necessary.
July	Beginning of the summer beetle emergence.	Continue scouting and sanitation.
	Infections begin to develop more slowly.	Continue to destroy root grafts where necessary.
August	Summer beetle emergence continues.	Scouting becomes more difficult as other stress factors affect trees.
September	Summer emergence declines. Beetles seek diseased and other declining elms in which to breed.	Continue scouting and sanitation.
October	Beetle larvae begin to overwinter beneath elm bark.	All routine pruning should be performed in the dormant season. Limbs pruned when beetles are active may initiate beetle breeding attacks.
November December January		All routine pruning should be performed in the dormant season. Evaluate control program and plan strategy for next year.

Appendix II

Elms susceptible and resistant to Dutch elm disease.

	Elms susceptible to Dutch elm disease
American elm	*Ulmus americana* L.
Winged elm	U. *alata* Michx.
Slippery elm	U. *fulva* Michx.
Rock or cork elm	U. *thomasii* (racimosa) Sarg.
September elm	U. *serotina* Sarg.
	Elms resistant[1] to Dutch elm disease
Smooth-leaved elm	*Ulmus carpinifolia* Gleditsch Cultivars: 'Bea Schwarz', 'Christine Buisman', 'Sarniensis'.
Dutch elm	*Ulmus* x *hollandica* Mill. (*U. carpinifolia* x *U. glabra*) Cultivars: 'Groeneveld', 'Commelin', 'Plantyn', 'Dodoens', 'Lobel'.
Chinese elm	*Ulmus parvifolia* Jacq.
Siberian elm	*Ulmus pumila* L.
Sapporo Autumn Gold elm	*Ulmus pumila* x *U. japonica* (Rehd.) Sarg.
Urban elm	(*Ulmus* x *hollandica* Mill. 'Vegeta' x *U. carpinifolia* Gleditsch) x *U. pumila* L.
Himalayan small-leaved elm	*Ulmus villosa* Brandis ex Gamble
	Zelkova resistant to Dutch elm disease
Japanese Zelkova	*Zelkova serrata* (Thumb.) Mak.

[1]Resistance is not immunity and is found among these species and cultivars in varying degrees.

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